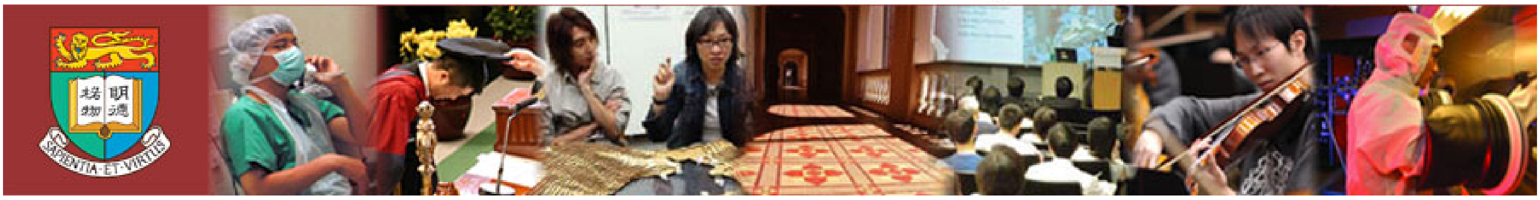

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|---|---|
| Title | Cross-sectional investigation of Chinese male and female adolescents' nasal cavities with rhinometry |
| Author(s) | Ng, Wing-yi; 吳穎怡 |
| Citation | |
| Issued Date | 2009 |
| URL | http://hdl.handle.net/10722/173680 |
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# Cross-sectional Investigation of Chinese Male and Female Adolescents' Nasal Cavities with Rhinometry

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A dissertation submitted in partial fulfilment of the requirements for the Bachelor of Science (Speech and Hearing Sciences), The University of Hong Kong, June 30, 2009.

## Abstract

The aims of the study were to measure nasal cavity parameters in Chinese adolescents and to investigate effect of age and gender in nasal cavity parameters. Forty-three male and forty-one female adolescents, ranging in age from 10 to 18 years were included. Nasal cavity parameters, including nasal volumes, cross-sectional areas and minimal cross-sectional areas were measured by Acoustic Rhinometry (AR) and analyzed with regard to age and gender. Although no significant age or gender difference was noted in all nasal cavity parameters, the current findings confirmed with the previous findings that steady growth of nasal cavity was noted during the stage of adolescence. The study has provided health-allied professionals and clinicians normative reference values in studying nasal diseases.

Cross-sectional Investigation of Chinese Male and Female Adolescents' Nasal Cavities with Rhinometry

The functions of nasal cavity, which referred to the first part of airway, include lubrication of inhaling air, trapping of dust, protection of the respiration mechanisms and provision of olfactory information (Illum, 2000). Additionally, nasal cavity was described as an important organ that helps the modulation of speech sounds (Fant, 1970). As stated by Hilberg (2002), “normal speech development and phonetics may also be associated with normal conditions in the first part of the airway – the nasal cavity and the pharynx” (p.6).

As nasal cavity serves a number of important functions, partial or total nasal obstruction can bring about different pathologic conditions such as sleeping disorders and rhinitis (Hilberg, Jackson, Swift, & Pedersen, 1989; Mohebbi, Farhadi, & Erfan, 2008). Adenoid hypertrophy, which was the enlargement of adenoid, was one of the common causes of nasal obstruction found in children (Grymer, Hilberg, Elbrond, & Pedersen, 1989). According to Kim, Kang and Yoon (1998), surgical procedures, for example adenoidectomy and tonsillectomy, would be used on patients suffering from total nasal obstruction. Before operations, nasal patency can be subjectively measured by clinicians and patients using Visual Analog Scale (VAS) (Zhang et al., 2004) or objectively measured by measuring minimal cross-sectional areas in nostrils (Grymer et al., 1989). Since physical properties of nasal cavity are closely related to nasal diseases, obtaining normative reference values is important in studying nasal pathology and making assessments on patients with nasal diseases.

*Past literature on nasal cavity measurements using non-AR technology*

Physical properties of nasal cavity have been quantified and evaluated using different methods in the past, including rhinomanometry, radiological method and optical method. However, they had their limitations in obtaining normative reference values and were discussed below.

*Rhinomanometry: pressure-flow technique.* Pressure-flow techniques have been used in defining nasal cavity parameters in children and adolescents (Warren and Laine, 1991; Warren, Lehman and Hinton, 1990). The use of the technique was based on an assumption that the pressure passing through different parts of the nasal cavity would be different as indicated by the airflow rate. Cross-sectional areas in the nasal cavity can be estimated from different airflow rates (Warren and Laine, 1991). However, Miyahara, Ukai, Yamagiwa, Ohkawa and Sakakura (1997) pointed out that the shortcomings of this technique were that “high degree of subject co-operation is required and the method can be time-consuming” (p.265).

*Radiological methods: computerized tomography and magnetic resonance imaging.* Computerized tomography (CT) has been used to investigate the difference in nasal structures between patients with nasal diseases and normal controls (Aslan, Yilmazer, Yildrim, Akkuzu, & Yilmaz, 2009). Besides, CT and Magnetic resonance imaging (MRI) were also used to provide images for different lesions at nasal cavity (Branstetter & Weissman, 2005). However, radiological methods may give unnecessary radiologic exposures (Wang, Berenheim, Kaufman,

& Clement, 1997); they are not suitable to obtain normative reference values when a large number of participants are involved.

*Optical method.* Rhinoscopy can visualize different parts of nasal airway and has been used in investigating the size of adenoid in children (Wang, Bernheim, Kaufman, & Clement, 1997; Zedalis et al., 1989). However, rhinoscopy is invasive and might not be the most ideal means to evaluate nasal cavity (Hilberg, 2002).

*The use of AR technology*

Unlike the previous methods, Acoustic Rhinometry (AR) was a non-invasive, simple means to measure nasal cavity. AR was firstly applied in measurements of nasal cavity by Hilberg et al. (1989). Since then, it has been extensively used to measure volumetric values for different parts in upper airway (Eckmann, Glassenberg, & Gavriely, 1996), to investigate effect of medication in allergic patients (Terada et al. 1998), to quantify morphological measurements of nasal tract in different races (Corey et al., 1998), to study nasal airway size in patients with cleft-palate (Kunkel, Wahlmann, & Wagner, 1997) and to study patients with sleeping disorders (Gelardi et al., 2007).

The accuracy and precision of AR has been well validated by comparing its measurement with other objective measurements. Corey, Gungor, Nelson and Fredberg (1997) reported a high correlation in decongested nasal airway between measurements of MRI and AR. A significant correlation between CT-scan and AR in defining the cross-sectional areas in the anterior part of the nasal cavity, which was the areas located between 0 cm and 6 cm from the nostrils, was reported (Min & Yang, 1995; Terheyden, Maune, Mertens, & Hilberg, 2000). Due to its non-invasive, simple and accurate nature, AR has been adopted in this study to define normative reference values of nasal cavity parameters.

*Literature on nasal cavity measurement using Acoustic Rhinometry (AR)*

To date, there were a number of studies using Acoustic Rhinometry (AR) to provide normative reference values for nasal cavity. Relationships between age, sex, height, weight, race and nasal cavity parameters have been studied. Corey, Gungor, Nelson, Liu and Fredberg (1998) have presented normative values of nasal volumes and nasal cross-sectional areas in 160 participants in four races: black, white, Asian and Hispanic. They concluded that effect of race, but not effect of age, was significant in nasal cross-sectional areas in adults. Therefore, it is necessary to obtain normal reference values of nasal cavity parameters to assess patients with nasal diseases objectively and study nasal pathology in different counties.

Measurements on normative reference values using AR have been described in adult population and the pediatric population. However, adolescent population was seldom involved. Normative reference values in adult groups were reported in different countries such as Iran (Mohebbi et al., 2008) and Thailand (Tantilipikorn, Jareoncharsri, Voraprayoon, Bunnag, & Clement, 2008). In both studies, no significant effect of sex in total nasal volumes and total minimal cross-sectional areas was reported. A study by Straszek et al. (2008) reported normative reference values of nasal volumes and minimal cross-sectional areas in 256 white children, aged from 4 to 13. They concluded no gender difference was noted in those nasal parameters. It implied that the growth rate of nasal cavity between boys and girls in the stage of childhood was similar. However, the difference in values of nasal cavity parameters between boys and girls in the stage of adolescence, which can be useful in study nasal pathology in adolescents, was not investigated.

*Nasal cavity measurements in Chinese population*

As normative reference values of nasal cavity parameters can be varied according to different races (Corey et al, 1998), they should be established specially for Chinese population in order to study nasal diseases in China. There were a few studies quantifying normative reference values of nasal cavity in Chinese pediatric and adult populations. Qian, Chen, Chen and Haight (2007) measured nasal volumes and minimal cross-sectional areas in a total of 234 children aged 4 to 5 years old. They concluded there was no age and gender difference in both nasal parameters. A study by Ma and Yu (1997) divided 176 Chinese adults, aged from 20 to 60, into five age groups and investigated effect of age and gender in nasal cavity parameters using AR technology. Unlike studies conducted in other countries which found no gender difference in the stage of adulthood, they reported that males have significantly greater nasal minimal cross-sectional areas and nasal volumes than the females. However, when the age of adults were restricted to age 20 to 30 in another study (Wang, Zhang, & Lian, 1999), no significant gender difference in nasal mean cross-sectional areas, nasal cavity volumes were noted. Additionally, as Wang et al. (1999) pointed out, “China is a geographically-wide country and natural environment in each region varies greatly and thereby affecting the accuracy of AR measurements (translated into English by the author)" (p.65). It implied that normative reference values for nasal cavity parameters should be established in different regions in China.

Report of normative reference values in nasal parameters in Chinese adolescents was especially scarce. The only study was the one carried out by Wang, Zheng and Dong (1997). They investigated nasal cavity parameters in 1,355 Chinese participants who aged from 3 to 76 years old using AR technology. They reported that there was gender difference found in nasal minimal cross sectional areas and distances of minimal cross sectional areas from nostrils in adult group. The values of both parameters were significantly higher in males than the females. They also suggested rapid growth of nasal cavity was observed from the stage of childhood and adolescence. However, the actual age range for children and adolescents was not clearly stated in the study. Therefore, the actually effect of age and gender in nasal cavity parameters in the stage of adolescence, which were scarce in the past studies, still needed further investigation.

*Aims of the study*

Despite reported normative reference values of nasal cavity in different populations, little is known in Chinese adolescent population. Information on this should be useful in evaluation of nasal pathology. This study was conducted a) to obtain normal values of nasal cavity in male and female Chinese-speaking adolescents, b) to compare normative data of nasal cavity measurement with regard to sex and age. The major hypotheses of the study were 1) growth of nasal cavity increases with age in adolescence and 2) growth of nasal cavity in male adolescents differs from that in female adolescents.

## Method

*Participants*

This study included eighty-four participants, forty-three males (51.2%) and forty-one females (48.8%), ranging in age from 10 to 18. They were recruited from one primary school and two secondary schools. They were divided into three age groups, 10 to 12 years, 13 to 15 years and 16 to 18 years. Prior to the measurement, height and weight of all participants were measured by a plastic ruler and a light portable weight respectively. The height and weight of all participants matched the height and weight of the corresponding age group of Hong Kong adolescents reported in previous study (Liang, Xie, Liu, & Liang, 1996). All participants were screened for absence of the following: (1) structural nasal anomalies, (2) any upper respiratory infection, allergy, cold and nasal obstruction at the time of testing, (3) speech and language problem using a questionnaire attached in Appendix A. All participants passed a hearing screening test performed at 25dB HL at 250, 500, 1k, 2k, 4k, 8 kHz binaurally. Informed written consent forms were all signed by parents before the measurements. The demographic information for the participants was presented in *Table 1*.

*Table 1.* Demographic data for male and female adolescents from three groups

| | Age groups | | | | | |
|---|---|---|---|---|---|---|
| | 10 – 12 | | 13 – 15 | | 16 – 18 | |
| | Male (N = 11) | Female (N = 14) | Male (N = 12) | Female (N = 13) | Male (N = 20) | Female (N = 14) |
| Age (yrs) | 10.82 | 10.70 | 14.04 | 13.81 | 16.98 | 16.84 |
| SD | 1.00 | 0.99 | 0.90 | 0.90 | 0.82 | 0.89 |
| Range | 9.50 -12.50 | 9.66 – 12.58 | 12.67 – 15.33 | 12.75 – 15.50 | 15.58 – 18.25 | 15.83 – 18.25 |
| Height (cm) | 142.66 | 146.24 | 165.50 | 155.15 | 171.00 | 158.79 |
| SD | 7.75 | 9.83 | 14.24 | 4.90 | 5.45 | 3.34 |
| Range | 134.00 – 156.00 | 130.00 – 163.00 | 134.00 – 177.00 | 144.50 – 163.00 | 157.00 – 177.50 | 152.00 – 163.00 |
| Weight (kg) | 34.45 | 39.07 | 52.68 | 45.47 | 61.52 | 51.71 |
| SD | 6.68 | 11.15 | 11.12 | 9.51 | 8.45 | 4.32 |
| Range | 27.00 – 45.00 | 28.00 – 69.00 | 33.00 – 67.00 | 30.00 – 58.00 | 47.00 – 78.00 | 45.00 – 56.00 |

*Equipment for measurements: Acoustic Rhinometry*

An Eccovision acoustic rhinometer (E. Benson Hood Laboratories, 1998) was used to evaluate nasal cavity of each participant. The acoustic rhinometer comprises a control unit for data processing and a wave tube connecting to the nostril. The control unit was connected with a monitor and a keyboard. The major components were shown in *Figure 1*.


*Figure 1.* An Eccovision acoustic rhinometer (E. Benson Hood Laboratories, 1998): equipment to measure nasal cavity parameters; 1 =wave tube with a nose tip; 2 =calibration tube; 3 =control unit; 4 =computer monitor illustrating a rhinogram

The analysis principles were described in previous study (Hilberg et al., 1989) and were illustrated below. A short-duration acoustic wave was emitted through the loudspeaker and directed into the wave tube and then to the nose. The incident wave was directed to travel along the superior airway. A number of reflected waves were generated after passing through the nasal cavity. A microphone was used to identify this short-duration acoustic wave. A digital computer was utilized to estimate the allocation of the cross sectional areas by sampling the recorded signals. An acoustic rhinogram, which referred to normal area-distance graph with cross-sectional area of the nasal cavity at the y-axis and the distance from the nostrils as x-axis has been attained. Nasal cavity parameters of interest, which were nasal volume between nostril

(0cm) and a distance of 6cm into the nose, cross-sectional areas and minimal cross-sectional area were obtained for each participant. Volume between nostril (0cm) and a distance of 6cm was selected for analysis according to the operation manual. Nasal minimal cross sectional area (MCA) was defined as the first dip marked in the rhinogram. The first (CSA1), second (CSA2) and third cross sectional areas (CSA3) referred to the first, second and third valleys shown in the rhinogram.

*Procedures for measurements*

According to the operational manual of the acoustic rhinometer (E. Benson Hood Laboratories, 1998), the procedures for measurements were as follows.

1. All participants were asked to sit upright in a chair in a quiet room. They were asked to face the experimenter. At the beginning of each test day, the rhinometer was calibrated using a calibration tube provided by the manufacturer.
2. A sanitized nose tip was placed onto the wave tube of the rhinometer. A thin layer of lubriderm was applied on the nose tip to ensure a tight seal between nose tip and the nostril. The wave tube was positioned beneath the participant’s nostril with the angle of nose tip slanting towards the septum. Care was taken to prevent deformation of the nose and the obstruction of the nose by lubriderm.
3. During the test, the participant was asked to hold their breaths for a few seconds, not to move their tongues and not to swallow thereby ensuring accurate measurement.

4. Two most comparable rhinograms were obtained for each nostril for each participant. The values for each participant were based on the average of these two rhinograms.

*Data & statistical analysis*

Homogeneity tests of age and gender were performed to all nasal cavity parameters. All data in each age group and gender group were found to be homogenous at a significance level of 0.05. The age difference and gender difference of nasal cavity parameters in the participants were examined. A two-way analysis of variance (ANOVA) test was performed using age and gender as two independent variables and other nasal cavity parameters (nasal volumes, CSA1, CSA2, CSA3, MCA) as dependent variables. The significant level of the test has been set at .05. All statistical analyses were performed using SPSS version 16.0.

*Reliability of measurements*

As a measure of intra-rater reliability, nasal volume, left and right cross-sectional areas and minimal cross-sectional areas of eight participants were randomly selected for re-analysis by the same investigator. As a measure of inter-rater reliability, nasal volume and minimal cross-sectional areas of eight participants were randomly selected for re-analysis by another investigator. The results of the intra-rater reliability and inter-rater reliability test including absolute mean difference and Pearson's correlation coefficient were shown in *Table 2*. The correlations were highly significant ($p<.01$) for all measured nasal cavity parameters for both inter-examiner reliability and intra-examiner reliability.

*Table 2.* Examiner reliability data for intra-rater reliability and inter-rater reliability measurements of nasal cavity parameters

| | Intra-rater | | | | Inter-rater | | | |
|---|---|---|---|---|---|---|---|---|
| Nasal cavity parameters | Original test | Second test | Absolute difference | Pearson *r* | Original test | Second test | Absolute difference | Pearson *r* |
| Nasal volumes ($cm^3$) | 17.99 | 17.74 | 0.25 | 0.95 | 17.99 | 19.05 | 1.06 | 0.88 |
| LCSA 1 ($cm^2$) | 0.88 | 0.88 | 0.00 | 0.98 | 0.88 | 0.91 | 0.03 | 0.86 |
| LCSA 2 ($cm^2$) | 1.78 | 1.71 | 0.07 | 0.98 | 1.78 | 2.08 | 0.30 | 0.78 |
| LCSA 3 ($cm^2$) | 2.67 | 2.83 | 0.16 | 0.97 | 2.67 | 3.22 | 0.55 | 0.76 |
| RCSA 1 ($cm^2$) | 0.96 | 0.99 | 0.03 | 0.99 | 0.96 | 0.94 | 0.02 | 0.94 |
| RCSA 2 ($cm^2$) | 2.11 | 2.22 | 0.11 | 1.00 | 2.11 | 2.19 | 0.08 | 0.95 |
| RCSA 3 ($cm^2$) | 3.09 | 2.93 | 0.16 | 0.98 | 3.09 | 3.26 | 0.23 | 0.82 |
| Min. CSA ($cm^2$) | 0.64 | 0.65 | 0.01 | 0.98 | 0.64 | 0.59 | 0.05 | 0.93 |

Abbreviations: CSA, Cross-sectional areas; L, Left; R, Right; Min. CSA, minimal cross-sectional area

## Results

The group means and standard deviations of nasal volume, cross-sectional area (CSA) in left and right nostrils and minimal cross-sectional area (MCSA) of male and female participants in three age groups were listed in *Table 3*.

*Table 3.* Means and Standard Deviations of Nasal Cavity Parameter for three age groups

| | Age groups | | | | | |
|---|---|---|---|---|---|---|
| | 10 – 12 years | | 13 – 15 years | | 16 – 18 years | |
| | Male | Female | Male | Female | Male | Female |
| | Mean (SD) | Mean (SD) | Mean (SD) | Mean (SD) | Mean (SD) | Mean (SD) |
| Nasal volumes ($cm^3$) | 14.77 | 14.45 | 16.51 | 13.96 | 17.64 | 16.78 |
| | (5.03) | (4.02) | (6.36) | (3.81) | (6.49) | (4.20) |
| LCSA 1 ($cm^2$) | 0.66 | 0.71 | 0.72 | 0.72 | 0.93 | 0.63 |
| | (0.22) | (0.14) | (0.23) | (0.14) | (0.31) | (0.14) |
| LCSA 2 ($cm^2$) | 1.31 | 1.28 | 1.52 | 1.33 | 1.79 | 1.50 |
| | (0.57) | (0.33) | (0.79) | (0.45) | (0.76) | (0.55) |
| LCSA 3 ($cm^2$) | 2.17 | 1.98 | 2.34 | 2.02 | 2.68 | 2.32 |
| | (1.31) | (0.62) | (1.44) | (0.70) | (1.57) | (0.88) |
| RCSA 1 ($cm^2$) | 0.82 | 0.81 | 0.84 | 0.73 | 0.85 | 0.84 |
| | (0.20) | (0.22) | (0.35) | (0.25) | (0.40) | (0.31) |
| RCSA 2 ($cm^2$) | 1.71 | 1.66 | 2.00 | 1.49 | 2.06 | 2.12 |
| | (0.52) | (0.79) | (1.02) | (0.62) | (1.09) | (0.80) |
| RCSA 3 ($cm^2$) | 2.89 | 2.91 | 2.80 | 2.33 | 2.83 | 3.69 |
| | (1.19) | (0.08) | (1.38) | (1.16) | (1.49) | (1.17) |
| Min. CSA ($cm^2$) | 0.55 | 0.54 | 0.55 | 0.54 | 0.61 | 0.59 |
| | (0.08) | (1.74) | (0.11) | (0.06) | (0.12) | (0.10) |

Abbreviations: CSA, Cross-sectional areas; L, Left; R, Right; Min. CSA, minimal cross-sectional area

A two-way analysis of variance (ANOVA) test was performed to investigate the effect of age and gender on nasal cavity parameters. In the analysis, age and gender were the two independent variables. Nasal cavity parameters, including nasal volumes, first cross-sectional area (CSA1), second cross-sectional area (CSA2), third cross-sectional area (CSA3) in left (L) and right (R) nostril and minimal cross-sectional area (MCSA) were the dependent variables. Statistical analyses showed that age and gender were not significant variables for all nasal cavity parameters.

Among all eight nasal cavity parameters, nasal volumes and minimal cross-sectional areas were of particular interest as they were the major parameters reported in past literature and they have important clinical implication in study of nasal diseases (Miyahara et al., 1997). The growth trend of nasal cavity in terms of nasal volumes and minimal cross-sectional areas between male and female adolescents in each age group were shown in *Figure 2* and *Figure 3*.

*Growth of nasal volumes across age groups*

Though the effects of age and gender were not significantly different at the .05 level, both male and female adolescents demonstrated a trend towards greater nasal volume across three age groups as shown in *Figure 2*. Additionally, males have a greater nasal volume than females in each age group. From *Figure 2*, nasal volumes showed steady increase across three age groups in male adolescents. Nasal volumes between age group 10 – 12 and age group 13 – 15 were similar in female adolescents with the highest nasal volumes noted in age group 16 – 18.

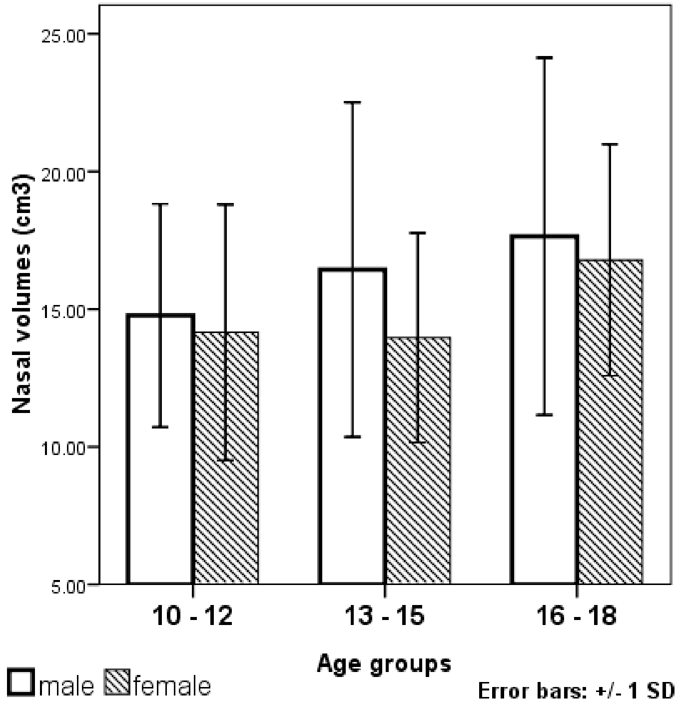


*Figure 2.* Nasal volumes of male and female adolescents in three age groups

*Growth of minimal cross-sectional areas across age groups*

There was no significant age and sex difference in minimal cross-sectional areas at the .05 level. However, *Figure 3* showed a trend towards greater minimal cross-sectional area across three age groups. Besides, the minimal cross-sectional areas of males and females in age group 16 – 18 marked the highest when compared with those of the other two groups. Minimal cross-sectional areas between age group 10 – 12 and age group 13 – 15 were similar. Across all three age groups, males have a greater minimal cross-sectional area than females.

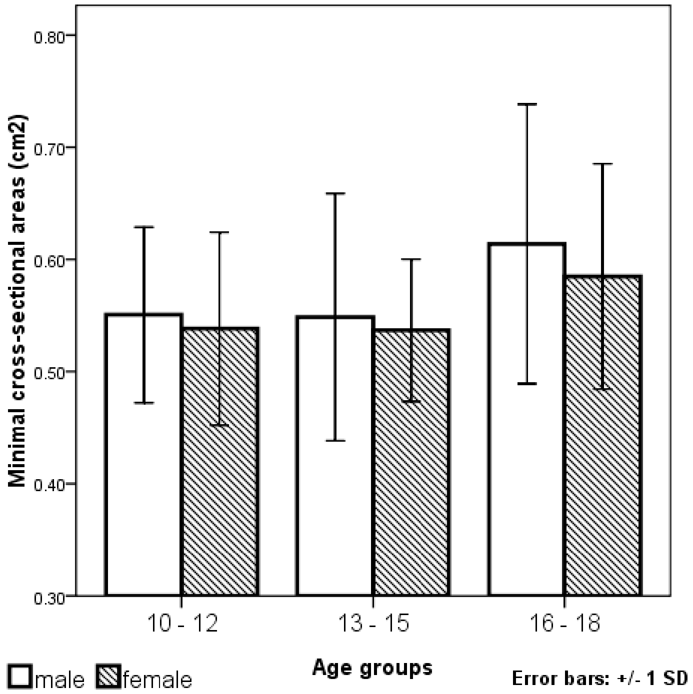


*Figure 3.* Nasal minimal cross-sectional areas of male and female adolescents in three age groups

## Discussion

This study was designed to provide normative data for nasal cavity parameters for Chinese male and female adolescents in Hong Kong, and to investigate the effects of age and gender on adolescents' nasal cavity parameters. This study applied Acoustic Rhinometry (AR) technology in measuring nasal cavity parameters. Though the current results showed no significant effect of age and gender in all nasal cavity parameters, this finding presented valuable normative nasal reference values in adolescent population, which were especially scarce up till now. In the following paragraphs, results of the current study will be compared with the results from previous studies. Clinical implications, limitation and future direction illustrated in this study will also be discussed.

Basically, the values of minimal cross-sectional areas presented in the current study showed agreement with the values reported in the previous study (Wang et al., 1997). In that study, Wang et al. (1997) reported that there was no significant difference in minimal cross-sectional areas with regard to age between age group 13 – 15 years and 16 – 17 years. Though the age groups used by Wang et al. (1997) were not as same as the age groups used in this study, the current findings also found no significant age difference between age groups 13 – 15 years and 16 – 18 years. This indicated that the growth of minimal cross-sectional areas was subtle during stage of adolescence. This was comparable to what Warren, Hairfield and Dalston (1990) suggested that nasal cross-sectional area increased only 0.032 $cm^2$ each year from age 6 to age 14. Consequently, being the smallest part in the nasal cavity, minimal cross-sectional areas might change little even there is a growth in the nasal cavity during the stage of adolescence.

However, the current finding was not entirely consistent with the previous data (Wang et al., 1997). They found that males have a significantly greater minimal cross-sectional area than females in age group 16 – 17. In this study, there was no statistically significant difference between male and female adolescents in age group 16 – 18 years for minimal cross-sectional area. However, the descriptive statistics showed that the pattern was similar to the findings of Wang et al. (1997). The difference of minimal cross-sectional areas between male and female adolescents was the greatest in the age group 16 – 18. One possible explanation for this discrepancy might due to different number of participants recruited in two studies. In this study, a number of 34 participants were included in the age group 16 – 18. The number was smaller than Wang et al. (1997)'s study, which have included a total of 113 participants in age group 16 – 17. The small number of participants recruited in this study might weaken the power of statistical analysis and gender difference was not shown.

Although no significant age and gender difference was revealed in the present study, the mean values of nasal volume showed gradual increase among three age groups for both male and female adolescents as shown in *Figure 2*. The observed increase suggested that nasal cavities grow gradually throughout the stage of adolescence. This supported previous findings (Wang et al., 1997; Warren, Hairfield, & Dalston, 1990) that nasal cavity marks a continuous growth during the stage of adolescence. The normative values of nasal volume in Chinese adolescents were not reported in previous studies. However, these values were greater than the values reported in Chinese adults (Ma & Yu, 1997). The discrepancy might due to the fact that the range of nasal volumes varies greatly according to the past studies. For example, nasal volumes of Asian adults reported in Corey et al. (1998) ranged from 10.12 to 40.43 $cm^3$ and nasal volume of adults in Taiwan ranged from 5.15 to 25.34 $cm^3$ in males and 5.57 to 36.87 $cm^3$ in females (Twu, Jiang, Wu, Hsu, 2003). In this study, the nasal volumes ranged from 7.80 to 29.22 $cm^3$. It showed that the range in the current study was similar to the previous two studies, which were very diverse. Since the nasal volumes can be varied greatly, the reported nasal volumes might be very different in different studies. Though values of the current finding were not comparable to those values reported in adult population, this study provided preliminary information on nasal volumes for Chinese adolescents.

The presented normative reference values for nasal cavity in adolescent population can have two important clinical implications. First, obtaining normative reference values will be useful for studying nasal pathology like rhinitis (Corey et al., 1998). According to Lee, Wong and Lau (2004), the prevalence of current rhinitis in children in Hong Kong was 35.1% in 2001. A study by Miyahara et al. (1998) showed that nasal volumes and minimal cross-sectional areas of patients with allergic rhinitis significantly decreased after a contact with histamine. Possibly, patients with acoustic rhinitis have different values in nasal cavity parameters. Besides, minimal cross-sectional areas were found to be positioned at the anterior part of the nasal cavity (Hilberg et al, 1989) and they were closely related to severity of nasal obstruction (Grymer et al. 1989). Clinicians can use the normative values as reference to make assessments of nasal cavity parameters in patients with allergic rhinitis and nasal obstruction.

Second, physicians may study effect of surgical procedures for nasal obstructions in children and adolescents with reference to normative values. Volumetric changes of nasopharynx after adenoidectomy, which was an operation for nasal obstruction, were reported in past studies (Cho et al., 1999; Elbrond, Hilberg, Felding & Andersen, 1989). Physicians can compare the values of nasal cavity parameters in patients with nasal diseases with normative reference values to determine the needs for surgical procedures and evaluate the outcome after the operations.

According to Lotta, Haavisto and Jukka (2008), some factors could affect reliability and accuracy measurements of AR technology. The following procedures have been adopted to control those factors so as to minimize the errors in the measurements. First, as background noise and temperature might affect the accuracy of the device, all measurements in the current study were taken in classrooms after school, which were quiet and temperature-stable. Second, the participants in this study were all asked to seat still and look straight during the testing. The angle of the rhinometer tube was always kept the similar angle during measurement. Third, normative data could only be used based on the assumption that there was no air leakage between the nose tip and the nostrils. In the present study, gel was always applied onto the nose tip to ensure a tight air seal. Also, all participants have been asked to hold their breaths during testing. This allows a more reliable measure of the nasal cavity parameters.

*Limitations*

One of the limitations in this study was the small number of participants which may weaken the power of the statistical analysis. In the future, a large number of samples can be drawn to determine a more accurate database for normative reference values of nasal cavity. Additionally, only adolescents from age 10 to 18 were included in this study. More information on normative reference values in younger children can be obtained to provide a more complete database.

*Future directions*

AR technology was a simple and non-invasive tool for providing quantified values of nasal cavity as demonstrated in this study. This technology can be adopted in further studies to investigate the relationship between nasal cavity parameters and acoustic properties of nasal sounds. Dang, Honda and Suzuki (1994) studied the relationship between acoustic and morphologic properties of nasal cavity on six participants using Magnetic Resonance Imaging

(MRI). They suggested that the asymmetrical nature of nasal cavity should be considered during investigation of nasal sounds. However, the actual relationship between nasal cavity parameters and production of nasal sounds was not depicted. With non-invasive nature, AR technology can be applied on a larger number of participants to further investigate the relationship between nasal cavity parameters and production of nasal sounds. That would give more insights on speech production mechanism.

Moreover, further study can be focused on nasal cavity measurement in patients with velopharyngeal insufficiency (VPI). Change of nasal resistance in patients with VPI during production of a plosive sound was reported in previous study (Liu, Warren, & Dalston, 1991). However, the actual volumetric or area changes in nasal cavity parameters were not clearly stated. Researchers may use normative reference values provided in the current study to compare with the nasal cavity parameters in patients with VPI. The relationship on change of nasal cavity parameters and production of speech sounds can be explored.

## Conclusion

Normative reference values of nasal cavity parameters in Chinese adolescents were obtained by Acoustic Rhinometry in this study. The mean values of nasal volumes and minimal cross-sectional areas showed a general increasing trend across the age groups. This current finding confirmed with the previous studies that nasal cavity grows during the stage of adolescence. The study provided valuable information for researchers and clinicians to study nasal pathology and make objective assessment on patients with nasal disease.

**Acknowledgements**

I would like to express my deepest gratitude to my supervisor, Dr. Steve Xue, for his kindness and valuable suggestions on my work. I also appreciate all the teachers and participants for their kindness and willingness to participate in this study. I wish to give special thanks to Mr. Ho, H. L., my former school teacher, for all his assistance in recruiting participants in this study.

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**Appendix A.** The questionnaire for every participant about their background.

# 有關青少年鼻腔結構的發展研究

# 參加者個人背景問卷

感謝閣下參與是項探討青少年鼻腔結構發展的研究。在開始進行儀器測量前，請先完成以下問卷，部分問題可能涉及閣下的私隱，所有資料只作研究用途，個人資料將絕對保密。完成後請在右下方簽署作實。

第一部分：請填寫以下資料：

| | |
|---|---|
| 姓名 | |
| 性別 | |
| 年齡及出生日期 | |
| 身高 | cm |
| 體重 | kg |
| 聯絡電話 | |

第二部分：請在正確的位置填上✓：

| | 是 | 否 |
|---|---|---|
| 1）你是否有任何說話能力的問題? | | |
| 2）你是否有任何聽力問題? | | |
| 3）你是否有任何呼吸系統問題? | | |
| 4）你是否曾經有任何神經受創? | | |
| 5）你是否曾經有兔唇/裂顎或其他面頰骨異常? | | |
| 6）你是否曾經接受面部/口部/顎骨的手術? | | |
| 7）現在，你是否患有傷風/感冒/鼻敏感/上呼吸道感染? | | |

請確認以上資料，並簽署作實。

參加者簽署：___________________________

日期：___________________________